Quantify Self-Organized Storage Capacity in Supporting Infrastructure-less Transportation Operation

Xiaoyan Hong*, Yingyan Lou†, Meng Kuai*, and Shuoping Wang ‡

*Department of Computer Science, University of Alabama, Tuscaloosa, AL 35487, USA

†Civil, Environmental and Sustainable Engineering, Arizona State University, Tempe, AZ 85287, USA

‡School of Computer Science, Zhejiang University City College, Hangzhou, China

{xhong,mkuai}@ua.edu, yingyan.lou@asu.edu, wangsp@zucc.edu.cn

ABSTRACT

This paper introduces an architecture for supporting transportation operation in an ad hoc way using the technologies of mobile sensing, computing and communication. The architecture utilizes the self-organized storage capacity formed at the intersections in metropolitan areas to deliver cyber traffic control signals to passing vehicles. It is built on top of the communication network in the forms of VANET and VDTN to support distributed computing using traffic data collected by mobile devices. The paper presents the key network components. The major challenge is the unique interdependence between the coordinated traffic signals and the persistence of the self-organized storage, an issue not being tackled in early work. The key impact factor is the pattern of the coordinated traffic signals. As a work-in-progress, the paper will present preliminary results in identifying the interdependence and its impact on the capacity of the self-organized storage. These results will lead to understandings on the sustainability of the architecture.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design

Keywords

Cyber traffic control; Self-organized storage; Vehicle communications; Mobile cloud

1. INTRODUCTION

Smart phones have becoming the main communication devices for obtaining travel related information. In addition, smart phones and on-board (vehicle) devices are able to collect traffic and driving behavior data in vast amounts and provide real time traffic updates to the backend servers. While communication infrastructures supports these information services in normal times, large-scale disasters can often cause physical damage to power, communication towers, etc, and lead to (partial) failures to the infrastructures. Often, transportation system facilities such as roadway fixtures can be damaged as well. The immediate aftermath can effectively paralyze the transportation system of the metropolitan area and its outskirts due to the lack of information about the situations, and equally important, the lack of coordinated traffic control. The results can lead to traffic congestion spreading far beyond the direct impact area and last for long hours.

We believe that mobile smart phones with sensing, computing and communication capabilities can play a critical part in alleviating the traffic congestions and stresses for the impacted people by self-organizing to a mobile cloud platform that supports a mobile cyber traffic control system. While existing work has proposed self-organized traffic lights for intersections [11][13], the Mobile Cyber Traffic Control System (MyTC) we propose bears a significantly different vision as it targets at achieving a better coordinated transportation operation over large-scale road networks. One of the major key components is the self-organized storage capacity formed by mobile devices at the intersections to support distributed computing and hosting of the cyber traffic signals, and to support distributed traffic data collection and aggregation [2][17]. The communications use WiFi interfaces on the smart phones via ad hoc networking (e.g, Apple's AirDrop, etc) (note: DSRC interfaces on mobile devices will grow their popularity.). Tremendous research results from vehicular ad hoc networks (VANETs) and vehicular delay tolerant networks (VDTN) should be ready to support communication needs for MyTC. The formation of self-organized storage and it being a cloudlet have been studied earlier [8][1][9]. The major contribution of this work to these related work resides on investigating the interdependence between the self-organized storage (co-existing with the vehicle communication network) and the transportation control logics via the dynamics of vehicular traffic.

In this paper, we introduce the architecture of MyTC and the challenges to maintain it due to lacking infrastructure support. As such, the interdependence between the traffic signals, hence vehicle mobility, and the sustainability of MyTC becomes the key impacting factor. Our question is "*can the storage capacity be maintained by vehicles distributed in a road network to the point that the transportation traffic control information can be sustained locally at intersections, as well as relayed to other parts of the road network for road traffic coordination?*". In this paper, we will identify and analyze the factors influencing the sustain-

MSCC'15, June 22-25, 2015, Hangzhou, China

DOI: http://dx.doi.org/10.1145/2757743.2757746.

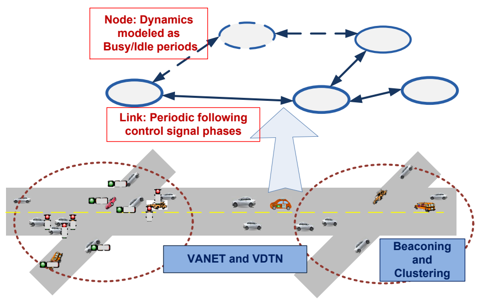

Figure 1: MyTC System Model

ability and the metrics to quantify the interdependence, especially the interdependence due to the coordinated transportation operation. Preliminary results about the impact on the capacity of the self-organized storage are obtained via controlled simulation scenarios. This research is work-in-progress, these results show further challenges posed on mobile sensing and computing for the mobile cloud platform to deliver MyTC.

The rest of the paper is organized as follows. Section 2 describes the architecture, the network model and the challenges. Section 3 introduces in detail the interdependence problem for self-organized storage capacity and essential metrics. The simulation results are given in Section 4. Section 5 presents a brief summary of related work, with Section 6 concludes the paper.

2. ARCHITECTURE AND CHALLENGES

2.1 Architecture

The major architectural element of MyTC is a group of vehicles (more accurately, the smart phones in the vehicles) in close vicinity that form a storage anchor (SA). SA has a geographical coverage per the defined size of the vicinity, such as a one-hop transmission range or a connected mesh component [8][10]. An intersection is more likely to become a location of SA because more vehicles can stay within each other's vicinity. Potentially such a SA will last longer compared to a sporadic location on a road.

In our context, SAs support location-based traffic data collection/aggregation and traffic control operations. Note that related work have pointed out that such self-organized vehicles can serve a general cloud platform for a wide-range of services [6]. SA bears the similar concept of a cloudlet [1][9]; but our work emphasizes the service aspects in the context of forming storage and computing capacity. Vehicles belonging to the same SA collaboratively hold (cache) pieces of information, process traffic data, and communicate with peers in the same SA or with approaching vehicles. Figure 1 shows a road segment where vehicles gather at the intersections and also scatter on the roads. It also shows that the SAs may or may not be connected all the time.

Each vehicle is assumed to include smart phones so that in addition to sensing, computing, networking units, GPS and digital maps, there is a user interface. The interface will show the phases of the traffic signals to the driver. The state-of-art VANET and VDTN results support MyTC in highly challenged vehicle network scenarios, such as large geographic areas, high density or intermittent connectivity. The underlying network functions include beaconing periodically to announce its presence and also to detect other vehicles in vicinity; broadcasting messages without or with targeted geographical regions (Geo-cast), and rebroadcasting if multiple hops are needed; routing and forwarding messages using popular VANET routing protocols when a group of vehicles are in a connected partition; and store-carry-forward-ing messages when a vehicle is not connected to any other immediately reachable vehicles using popular VDTN protocols. Specifically, this DTN solution to the intermittent connection issue relies on vehicles driving in the opposite direction. Existing work DV-CAST [14] has already proposed protocols that are able to integrate VANET and VDTN to count for the fact that these two network conditions occur frequently per vehicle distributions. There are also good early results of self-organizing vehicles into clusters (or rings) according to geographic location that can be used as building blocks to support distributed and collaborative computing of traffic data and host data at SAs [3][15].

Due to page limit, we limit our discussions to the most intriguing problem unique to the MyTC service, i.e., the mesh of SAs has spatial-temporal properties that depend on the dynamic vehicle traffic flows resulting from road traffic operations.

2.2 Challenges

The importance of coordinated transportation operation is clearly demonstrated in our case study of two intersecting major arterial roads in Tuscaloosa, Alabama. A study site of roughly 5 square-miles with more than 20 intersections was simulated using real-world data and a prevailing transportation simulation package. The results show that in a normal morning peak hour, the network-wide average speed is $22.20mph$, which reduces to only $7.00mph$ if all the intersections are operating under stop-controlled rules (as is likely the case after a major disaster and infrastructure break-down).

The challenge to the Mobile Cyber Traffic Control System is that the ability (time period, and caching capacity) of the SAs in maintaining/holding real-time transportation information highly depends on the traffic signals. The changes of the signal phases alter the mobility of the vehicles, which impacts the lifetime of an existing SA. In addition, the SAs at different intersections are highly correlated following the traffic control logic. Usually for transportation efficiency, traffic operations in an urban road system tend to coordinate traffic lights so to clear vehicles on one group of road segments quickly. As a consequence, these vehicles can create concentrations (i.e., SAs) at intersections of other road segments. Such an operation strategy creates spatial gaps between vehicles and can lead to disconnection of V2V communications. While VDTN still disseminates messages among SAs for MyTC, it can generate pro-longed message latency, leading to outdated road traffic signals at the receiving SAs. Conversely, a reliable V2V communication is often more easily achieved with denser and more uniformly distributed vehicular traffic (such as uniform speed and car convey), which may indicate suboptimal traffic operations. No existing work has investigated this issue.

Thus in this paper, we study how coordinated vehicle traffic control influences the dynamic occurrence and duration of SAs. Our focuses are on the metrics that are able to quantify the interdependence between the SAs and the coordinated vehicle traffic control.

3. ANALYZING INTERDEPENDENCE

3.1 Persistence of SAs

The persistence of a SA depends on the vehicular traffic flow. Or say, a SA sustains when vehicle flows consistently pass the intersection. Early work has used queueing model to calculate the mean information storage time at a location based on highway vehicle traffic, and the results were validated using city taxi traces [8]. However, the large-scale and complex urban environments poses quite different challenges as work in [8] also shown that urban environments can generate quite different vehicle traffic pattern compared to uninterrupted vehicle flow. The simple queue model will not be able to capture the complex vehicle traffic arrival and departure processes that enter and leave a SA.

Using a general $GI\,|D|\,\infty$ queue model, where the service time D is $transmissionrange/speed$, we can generate metrics to quantify the duration of the occurrence of a SA (the busy period), the duration of when a SA is not sustained (the idle period), the number of vehicles in the SA, and the duration of the cyclic pattern consists of the busy period and the idle period. Collectively, these metrics characterize the capacity of the SA assuming each vehicle has the same amount of storage to share. However, close form solutions cannot be obtained due to the complex arrival process in urban environments.

To study the impact from coordinated traffic operation, these metrics will be measured with particular interest in different traffic signal phases and offsets in order to show the dynamic occurrence and duration of SAs. We will use simulations to obtain insights to these properties.

3.2 Measuring recovery strategies

Since MyTC targets at coordinated traffic operation, the disappearance of a SA leaves the intersection to a stop-control operation, which in turn, reduces transportation efficiency established upon the current good-state coordination. Thus we study the performance relating to potential (SA) recovery strategies. Due to mobility, messages or data pertaining to one SA can be transmitted or carried to other SAs via either VANET or VDTN protocols. These messages or data can be aggregated road traffic volume, operation of the traffic signal parameters, etc. Thus, when a SA disappears from one intersection, it is possible to recover the signal control cycle and offset or to reconstruct them. For the former, vehicles traveling in the opposite or in-bound directions are able to establish the next occurrence of the SA because these vehicles have received the messages or data about the previous SA from vehicles left it. For the latter, no in-bound vehicles hold operation parameters of this SA, rather, they have data from the just-past SA. In this case, this SA can adjust operation parameters for itself based on the neighboring SA with additional considering factors such as distance, speed and traffic volume.

Thus, two metrics, namely recovery delay and reconstruction delay, are of importance. The recovery delay can be characterized using the idle period of SA because the previous operation parameters can be brought back from any in-bound traffic when the next SA is formed.

For the reconstruction delay, the complexity of a mixed VANET and VDTN needs to be considered together with factors of the distance between the two intersections, spatial distribution of vehicle density, transmission in the opposite travel direction, etc.. While three types of links exist: a single direct transmission, a multi-hop relay path (VANET case), and a store-carry-forward path (VDTN case), the VDTN case can contribute significantly to the delay. Therefore, the reconstruction delay will measure the message carrying time, which is calculated based on the travel time over the length of the road segments where connected VANET components do not cover nor direct transmission does. Again, while using these metrics for study the sustainability of MyTC, we are interested in how traffic coordinations play a role.

3.3 Traffic operation: local vs global

MyTC assumes a computing model that delivers the traffic operation local to each SA. The traffic data, though collected distributed, is propagated network-wide as long as the life time is valid. The vehicles are only engaged in maintaining a local SA and its traffic signal's phase collaboratively. On the other hand, the traffic operation (the signal phase parameters) can also be propagated network-wide with their life times, like the traffic data. In this case, each node may have a global view of the transportation operation. This latter approach has the problem that the data about traffic signals at far distance intersections can be useless, because either the vehicle does not head to them, or when the vehicle approaches them, new parameters are installed in reacting to dynamic traffic conditions. As such, propagating and storing global data can unnecessarily produce overhead to communication links and vehicle storages.

It is challenging to strike a balance in terms of how far the data about the traffic operation at one intersection should be propagated or how long it should be retained while traveling. Additional factors need to be considered in future research. They include: (1) the accuracy of sensed traffic data; (2) the travel routes of the vehicles; (3) the robustness of the adaptive traffic operation algorithms; and (4) the potentially reduced packet delivery success rate due to prolonged reconstruction delay caused by unpredictable vehicle mobility.

4. EMPIRICAL ANALYSIS

The goal of the simulations is to study how the correlations of traffic lights impact the capacity of the self-organized storage at SAs. The aforementioned metrics will be evaluated against controlled traffic signal configurations in a special-designed road system. We use SUMO [5] to simulate the controlled transportation scenarios including road map, traffic volume and signal phases. The formation of SA and communication links are abstracted using transmission range. The results will first show the mobility statistics of the simulation scenarios, and then the metrics for the SAs.

4.1 Controlled transportation scenario

We consider a main urban road with eight signaled intersections in a straight line and bi-directional vehicle traffic. The distance between each intersection pair sets to 1000 meters. The speed limit is 20m/s. The traffic is generated following the Poisson distribution with a two sending rates to compare the effects of traffic density. They are 0.5 car per second (dense case) and 0.25 car per second (sparse case) respectively. The majority of the vehicles are injected/removed from the two ends of the road, while a small percentage of cars are injected/removed from all the intersections. As such, the total number of vehicles on the road maintains relatively the same. The simulator SUMO is configured to each simulation lasts 3000 seconds. The warming-up time is 1000 seconds and the results are averaged over 10 runs with random seeds.

The cycle of the signal phase shift is the same for all the signals. In our simulation, each signal has 50 seconds red period and 50 seconds green period (denoted as 50:50). In order to evaluate the impact from the correlation between signals, each signal may start with a different offset in time, i.e., the starting time of the cycle at each signal has a relative offset. For example, if the routine of signal light 2 is 20 seconds later than the routine of light 1, the offset is 20.

To study the impacts from different offsets, we divided all signal lights into two groups. Signal light 1, 2, 3, 4 are in group ONE; signal light 5, 6, 7, 8 are in group TWO. Offsets inside each group (intersection pairs of 1-2, 2-3, 3-4 and 5-6, 6-7, 7-8) are pre-calculated to the “best case” for one direction (from intersection 1 to 8) , i.e., vehicles drive through the intersections without being stopped by the signals (the most efficient for transportation). Note that our control to the signal offsets for the “best case” is only effective for one direction. Traffic from opposite direction is not subject to the “best case” control. During the experiment, we change the offset of the pair between the groups ONE and TWO (the intersection pair 4-5). In the figures, the x-axis shows the offset configurations for each simulation run. With the two-groups setup, we are able to observe not only the best-case behaviors from intersections with each group, but also the dependence to traffic coordination from intersection 5. As such, many results will show curves for the intra-group and inter-group intersections.

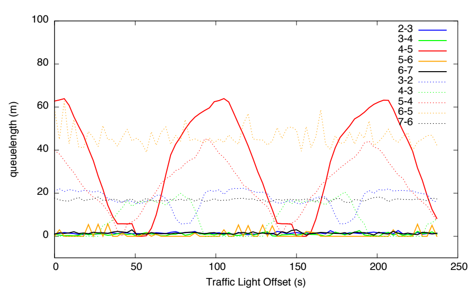

Figure 2: Queue length

Figure 2 explains the controlled transportation scenario by showing the average queue length at each road segment (identified as intersection pairs). The solid lines are for the traffic direction with the “best case” traffic signal configuration and the dashed lines indicate traffic in the opposite direction. As expected, the queue lengths of the intersection pairs inside each group are nearly zero for the “best case” setup, while those for the opposite direction show certain queue length, suggesting that the vehicles are not subject to the “best case” traffic signal configuration. Noticeably, intersection pair 4-5, where two groups connect, shows a different pattern from the rest of the intersection pairs. The figure shows repeated increasing and decreasing of the queue length corresponding to the change of signal light offsets. The smallest queue lengths occur when the offset is equal to a multiple of the “best case” offset configured inside each group. The result suggests that signal configurations have an impact on the queue length. The results of average seed confirm that the largest value occurs when the offset is equal to a multiple of the “best case” offset.

The results here further suggest that while the traffic of the best-case direction responds to signal control, the traffic of the opposite direction does not. Specifically, the latter shows a weaker relation which occurs at different offsets from the former. For example, the best cases of the queue length of the opposite direction occur at the lowest points on the dashed red line of 5-4 in Figure 2, which are different from the base cases of the line of 4-5. Such observation is important for understanding the following properties of SAs.

4.2 Measuring the capacity

To demonstrate the dynamic aspects of the storage capacity for each intersection, we use following calculations. We define an intersection is in *holding* state at the time period if there is at least one vehicle in its transmission range. In our simulation, we set statistic time period as 1 second and transmission range as 100 meters. The following metrics are used to quantify the properties of SAs at each intersection.

- *Mean holding size*: The holding size is the geographic area of a SA. The metric is calculated using the lengths of vehicular queues when an intersection is in *holding* state. Mean holding size is calculated by the mean value of the holding size at each *holding* state.
- *Mean holding density*: It is the area density calculated by the mean value of total number of vehicles within a transmission range at each time period.
- *Total holding time*: It counts for the duration that a *holding* state can last. It is the total time periods that the intersection is in *holding* state.
- *Mean recovery delay*: It measures the ability to recovery by in-bound traffic. It is obtained by counting the delay from one *holding* state to the next *holding* state.
- *Mean reconstruction delay*: It is the average delay for an intersection to receive messages carried back from a neighboring intersection. It is calculated using the minimal travel time from the neighboring intersections.

4.3 Results

As observed earlier, while there is a best-case coordinated traffic direction, traffic in the opposite direction does not respond to the schedule as its favorable configuration. Because the SAs are built with traffic from all the directions, such observation suggests that simply controls traffic in one direction may not yield traffic dynamics for SAs’ case. Our future work will use the traffic signal schedules generated from the transportation algorithms, which are optimized according to traffic of all the directions. In this paper, we present results of the two cases: traffic of the signal direction (best controlled) and traffic of both directions. Results obtained from traffic of both directions are realistic, but could be biased. Results obtained from traffic of single direction, though is not realistic, the patterns shown can suggest the trends when optimal traffic schedules are used.

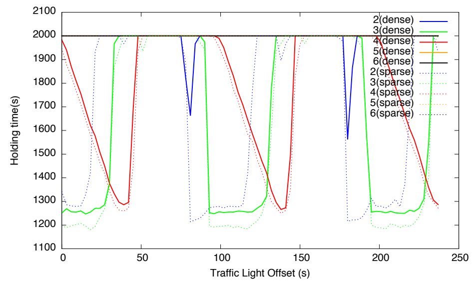

Figure 3: Total holding time (dual-direction)

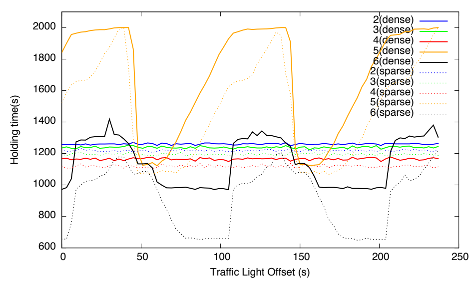

Figure 4: Total holding time (single-direction)

Figure 3 and Figure 4 shows total holding time for dual directions and single direction, separately. The figures show several interesting observations. First, in the dual direction case, holding time changes when offset changes. The repeated pattern suggests that the change is corresponding to the traffic coordination. Second, the holding times of intersections of 5 and 6 in Figure 3 are almost 100%. This is because when combined with opposite traffic, the intersections always have vehicle traffic because the opposite traffic is not subject to the same best-case traffic control. This can be validated as shown in the signal direction case in Figure 4. Both intersections of 5 and 6 (yellow and black lines) react to the change of offsets with a pattern of high and low. The intersections of 5, being directly impacted by the offsets, shows strong tendency in reacting to the traffic coordination configurations. Third, both figures show that traffic density plays a role in reacting to offsets. One demonstrates different shifts to the offsets, and the other is holding time. Figure 4 shows that dense traffic can produce longer holding time, especially for the single direction case. In addition, the total holding time in Figure 4 has similar trend with Figure 2, which means that longer queue can extend holding time.

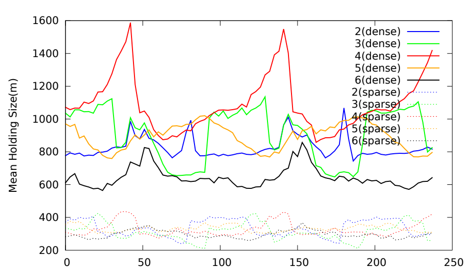

Figure 5: Mean holding size (dual-direction)

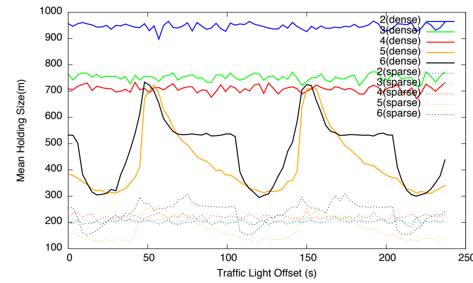

Figure 6: Mean holding size (single-direction)

Figure 5 and Figure 6 display the results of the mean holding size at intersections 4 and 5 with different signal light offsets. Both figures show repeated patterns in corresponding to the the circles when the offset increases. When traffic is sparse, the results show smaller holding sizes since less vehicles are present at road. It is interesting to notice that the peaks of the holding size occur when the correspondence that the holding time is at the lowest (see Figures 3 and 4), i.e., at the best-case offset configuration. This is because, when the traffic offset for intersection 4-5 are configured to match the best-case, vehicles pass intersections 4 and 5 without stop, leading to better spread out of their positions. Thus, for the dense case, the spacing between the cars are able to maintain larger connected groups around the intersection compared to the sparse case. More over, when investigating the single direction case, we found that the holding sizes of intersection 5 and 6 shows a strong dependency on the coordination of the traffic control. Figure 6 also shows that the intersections in group ONE behave differently from those in group TWO. That is because the signal offsets only change for intersection 5 for the purpose of studying the dependence. The intersections of group TWO are then affected by the offset change as well. On the other hand, those in group ONE experience best-case controls no matter how offsets change. So the holding sizes stay high.

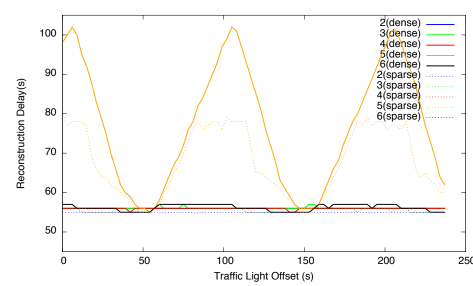

Figure 7: Mean reconstruction delay

Now we show results for the recovery strategies. In fact, the recovery delay is the idle period of SA. Given the fixed total simulation time, the results show patterns being the complement of the holding time. As such, here we only show the reconstruction delay in Figure 7. As discussed earlier, travel time dominates the delay. The figure shows that for most all the intersections the similar delay are expected when offset changes expect for intersection 5. This is because that only in-bound traffic matters for reconstruction. The reconstruction delay is longer than recovery delay because reconstruction only happens when recovery is not possible. The reconstruction will then need the vehicles to travel the entire distance between the two intersections in the worst case. The dependency to the offsets is clearly demonstrated through the repeatedly highs and lows along the curve.

5. RELATED WORK

Closely related work are in the aspects of self-organized storage and self-organized traffic lights. Self-organized storage or cloudlets is using vehicle-to-vehicle communication to maintain information in a certain area for a range of time, especially when there are less infrastructures. Issues such as overhead, reliability and performance are studied [18][4][6]. Though these works focus on improving self-organized storage from different aspects, they did not consider the influences from transportation, such as traffic lights. Song *et al.* [12] investigated the influence of traffic lights on data delivery when vehicles move between intersections. But our paper is different in that we analyze correlation between traffic lights and its impacts on self-organized storage capacity. Also, we introduce a system that can achieve coordinated transportation operation on top of self-organized storage.

Self-organized traffic lights, as known as Virtual Traffic Lights (VTL), are using vehicular communication and self-organized storage to support transportation operation and thus replace real traffic lights [11][13]. Different from those work, our work leverages VTLs to enhance self-organized storage capacity and uses traffic data sensed from vehicles to achieve coordinated transportation operation of multiple VTLs. There are also works about adaptive traffic lights using mobile sensing, computing and communication technologies [7][16]. While they offer inspirations on the additive control, they do not consider coordinated transportation operation over large-scale road networks as we do.

6. CONCLUSION

In this paper, we presented an architecture building on self-organized storage and mobile sensing, computing and communication to support transportation operation during aftermath of large scale disasters where infrastructures are not available. We present analysis and preliminary results to show the challenges for mobile sensing, computing and communication to support the architecture and the key approach capturing the interdependence and traffic signal coordination to address the challenges. The work is in progress. A few future directions are outlined in the paper.

7. REFERENCES

[1] Elijah: Cloudlet-based Mobile Computing. `http://elijah.cs.cmu.edu/`, Nov. 2013.

[2] R. Bauza, J. Gozalvez, and J. Sanchez-Soriano. Road traffic congestion detection through cooperative vehicle-to-vehicle communications. In *Local Computer Networks (LCN), 2010 IEEE 35th Conference on, Denver, CO*, pages 606–612, 2010.

[3] P. Fan. Improving Broadcasting Performance by Clustering with Stability for Inter-Vehicle Communication. In *IEEE 65th VTC 2007-Spring, Dublin, Ireland*, pages 2491–2495, 2007.

[4] D. Haritha and R. Lalitha. Cluster Based Neighbor Coverage Relaying (CBNCR)-A Novel Broadcasting Mechanism for Dissemination of Data in VANETs. *Computer Engineering and Intelligent Systems*, 5(9):36–43, 2014.

[5] D. Krajzewicz, J. Erdmann, M. Behrisch, and L. Bieker. Recent development and applications of SUMO - Simulation of Urban MObility. *International Journal On Advances in Systems and Measurements*, 5(3&4):128–138, December 2012.

[6] Y. Li and W. Wang. Can mobile cloudlets support mobile applications? In *INFOCOM, 2014 Proceedings IEEE*, pages 1060–1068, Apr. 2014.

[7] Z. Li, L. Elefteriadou, and S. Ranka. Signal control optimization for automated vehicles at isolated signalized intersections. *Transportation Research Part C: Emerging Technologies*, 49(0):1 – 18, 2014.

[8] B. Liu, B. Khorashadi, D. Ghosal, C.-N. Chuah, and M. H. Zhang. Assessing the VANET's Local Information Storage Capability under Different Traffic Mobility. In *Proceedings of IEEE Infocom 2010, San Diego, CA, USA*, pages 1–5, 2010.

[9] M. Satyanarayanan, G. Lewis, E. Morris, S. Simanta, J. Boleng, and K. Ha. the Role of Cloudlets in hostile Environments. *Pervasive Computing*, Oct. - Dec.:40–49, 2013.

[10] S. Smaldone, J. Harkes, L. Iftode, and M. Satyanarayanan. Safe Transient Use of Local Storage for VM-based Mobility. Technical report, Tech. Rep. CMU-CS-10-110, Computer Science Department, Carnegie Mellon University, Pittsburgh, PA, USA, 2010.

[11] C. Sommer, F. Hagenauer, and F. Dressler. A networking perspective on self-organizing intersection management. In *Internet of Things (WF-IoT), 2014 IEEE World Forum on*, pages 230–234, Mar. 2014.

[12] C. Song, W.-S. Yang, J. Wu, and M. Liu. Red or green: Analyzing the data delivery with traffic lights in vehicular ad hoc networks. In *Global Communications Conference (GLOBECOM), 2014 IEEE*, pages 64–69, Dec. 2014.

[13] O. Tonguz and W. Viriyasitavat. Cars as roadside units: a self-organizing network solution. *Communications Magazine, IEEE*, 51(12):112–120, Dec. 2013.

[14] O. K. Tonguz, N. Wisitpongphan, and F. Bai. DV-CAST: A Distributed Vehicular Broadcast Protocol for Vehicular Ad Hoc Networks. *Wireless Communications, IEEE*, 17(2):47–57, 2010.

[15] L.-C. Tung and M. Gerla. An Efficient Road-Based Directional Broadcast Protocol for Urban VANETs. In *Vehicular Networking Conference (VNC), 2010 IEEE, Jersey City, NJ, USA*, pages 9–16, 2010.

[16] J. Xu, W. Sun, N. Shibata, and M. Ito. GreenSwirl: Combining traffic signal control and route guidance for reducing traffic congestion. In *Vehicular Networking Conference (VNC), 2014 IEEE*, pages 175–182, Dec. 2014.

[17] F. Yan, M. Dridi, and A. El-Moudni. New Vehicle Sequencing Algorithms with Vehicular Infrastructure Integration for an Isolated Intersection. *Telecommunication Systems*, 50(4):325–337, 2012.

[18] T. Yan, W. Zhang, and G. Wang. DOVE: Data Dissemination to a Desired Number of Receivers in VANET. *Vehicular Technology, IEEE Transactions on*, 63(4):1903–1916, May 2014.